Integrating and Applying Internet Protocols with a Reconfigurable Software Radio - The Low Power Transceiver (LPT)

David J. Zillig

Network Support Group/Code 567 NASA Goddard Space Flight Center, Greenbelt, MD

William D. Horne, Ronald Pawlikowski, and Carl F. Kwadrat

ITT Industries, Advanced Engineering & Science Division, Reston, VA.

Abstract

Emerging reconfigurable software radio technology provides an opportunity to implement new spacecraft data system architectures that can support internetworking in space and on-board spacecraft. The digital processing capability of software-configurable radios can support internetworking while also enabling new on-board data system architectures and operations that integrate networking functions directly into the communications devices and processes.

The Low Power Transceiver (LPT) developed for the Goddard Space Flight Center (GSFC) provides an opportunity to test these internetworking capabilities of software configurable radios. The LPT is a modular, multi-channel software configurable radio that provides digital signal processing capabilities. The processing capability is used for communication functions, but it can also be applied to higher-level applications. The GSFC Communications and Navigation Demonstration on Shuttle (CANDOS) project plans to take advantage of the LPT's processing potential by integrating and demonstrating applications such as GPS-based onboard navigation and Internet Protocol (IP) based data transfers. A Space Shuttle flight in mid 2001 will host CANDOS, which will be the first space-based demonstration of the LPT. The paper discusses the LPT and the CANDOS project and provides a vision of using software radios in space internetworking and spacecraft on-board networking.

1. The Low Power Transceiver (LPT)

1.1 LPT Overview

The LPT, shown in Figure 1, provides an integrated two-way communications capability for satellites and an autonomous navigation feature for satellite applications. The communications features are compatible with the National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRSS) and Ground Network (GN) System threreby providing the flexibility needed to support a variety of NASA based Low Earth Orbiter (LEO) satellite missions. The software programmable feature of the LPT provides the capability of adapting the transceiver to an even broader scope of operations such as interplanetary missions or other specialized applications without changing the system hardware. The multiple low powered modes of operations of the LPT make the transceiver an ideal candidate for small satellite applications with significant power limitations.

The on-board Global Positioning System (GPS) navigation receiver collects radiometric GPS satellite range measurement data that can be used to make position and velocity estimates of the receiver. Static and time varying position estimates can be made depending upon the type of navigational algorithm that is incorporated in the LPT software. The autonomous navigation feature coupled with the low power operations requirements make the LTP an ideal candidate for use in satellite cluster missions as well as other applications with limited power budgets.

Figure 1. Low Power Transceiver

1.2 General LPT Capabilites

1.2.1 Hardware Architecture and Functions

Figure 2 shows the hardware architecture of the LPT. The LPT has two RF inputs, one for the TDRSS S-Band signals and the other for the GPS L-Band signals. The receiver/demodulator function downconverts the RF inputs to IF or baseband in preparation for analog-to-digital conversions. The digitized data is processed by the Sequential Digital Processor that extracts the TDRSS and GPS data from the incoming I and Q channels. Up to 12 signals of arbitrary modulation can be processed from either input band. This data is then processed by the Command and Data Handler/GPS Processor to provide telemetry data containing both TDRSS and navigation data. The telemetry data is BPSK or QPSK modulated and upconverted to S-Band for transmission to Tracking and Data Relay Satellites (TDRSs), GN stations, or other destinations such as cluster satellites. Receiver data rates are up the 300 Kbps uncoded and 150 Kbps coded. Transmit data rates are up to 300 Mbps. The receiver power consumption is less than 8 Watts while the transmitter has multiple output modes with a maximum of 25 Watts.

1.2.2 Programming Capabilities

The digital signal processing function of the LPT are directed by software algorithms that control the signal acquisition and demodulation of each of the 12 signal channels. The processing algorithms are maintained in LPT memory as code that is read by the digital signal processor similar to the manner in which the Central Processing Unit (CPU) of a computer reads computer programs from memory. New code can be loaded into the LPT at any time, thus making it possible to introduce new digital signal processing features at any time.

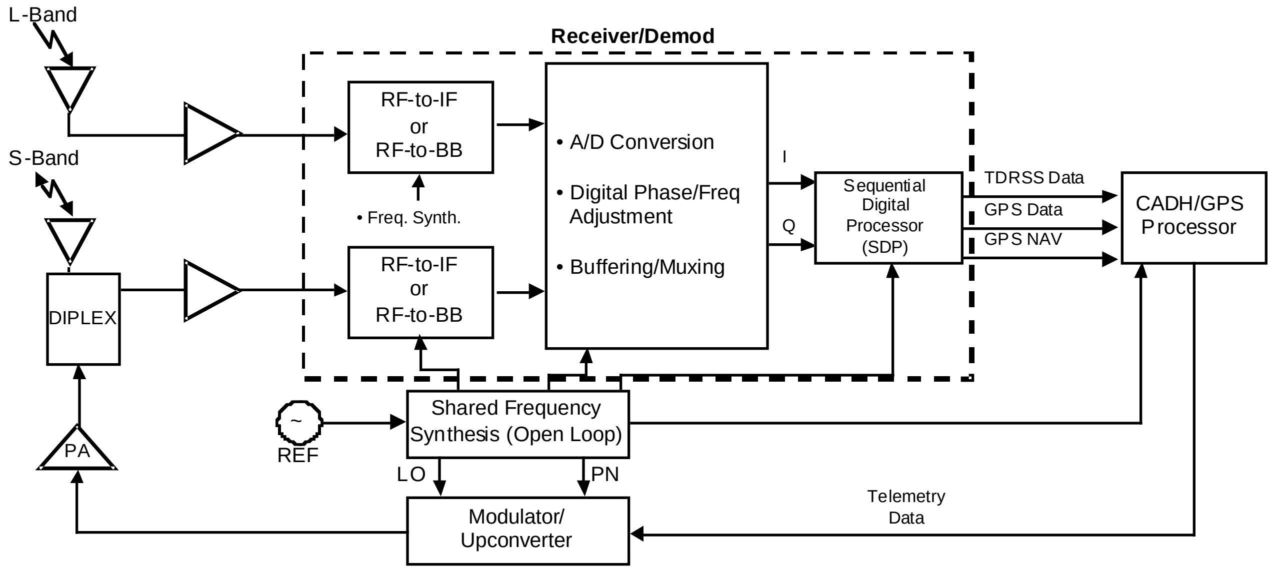

Figure 2. LPT Hardware Architecture

The LPT digital signal processing capacity is under utilized by the communication processing function thereby allowing other processing software functions to be added to the LPT and run concurrently with the communication signal processing algorithms. The extra processing bandwidth allows navigational algorithms to be included in the LPT as software to support the estimation of the transceiver's position and velocity as a function of time. Orbital motion applications requires that orbit prediction algorithms be added and radiometric data be gathered from the GPS satellites to provide geometric measurements from which the transceivers position and velocity can be estimated in real-time. The extra bandwidth can be used to provide other processing functions outside of the signal processing and navigational processing areas. These functions could be used to introduce new capabilities such as message routing to the LPT.

1.3 Potential LPT Applications

The current version of the LPT provides two-way communications with NASA's Space Network (TDRSS) and receives GPS signals. Future versions of the LPT will include connectivity to the NASA Ground Network. The LPT can be adapted for use utilized for a variety of missions including:

- Clusters and Formation Flying systems;
- Constellations of LEOs;
- Balloons; and,
- Interplanetary Missions.

2. CANDOS Experiment

2.1 CANDOS Overview

The GSFC Communications and Navigation Demonstration on Shuttle (CANDOS) project is the first space-based demonstration of the LPT. The project is implementing and integrating new capabilities into the LPT to demonstrate on-orbit Space Network (SN) communications, GPS-based onboard navigation, and LPT reconfiguration. Specifically, the LPT will be tested aboard a Space Shuttle flight using the Shuttle Small Payloads Project Hitchhiker (HH) carrier system. The demonstrations will be conducted during a Space Shuttle flight in mid 2001. During the CANDOS project, the LPT will demonstrate five major on-orbit functions: TDRSS SN Communications, GN Communications, On-Orbit Reconfiguration, Space-based Range Safety Technologies, and GPS Navigation.

2.2.2 Basic GN Communications

The LPT receives GPS signals for spacecraft navigation support and provides both forward and return data communication links respectively from and to the Ground Network Facilities. Merrit Island (MILA) ground stations, Wallops Flight Facility (WLPS) ground stations, and Dryden Flight Research Facility (DFRC) ground stations form the Ground Network (GN) Facilities. The LPT will provide the user portion of an S-band telecommunications link via the Ground Network. The forward link is defined as the communications path originating at a ground station to the LPT. The return link is defined as the reverse path, from the LPT to the ground station.

The CANDOS Processor is designed to automatically configure and enable the transmitter for GN communications upon successful acquisition of a GN forward link signal. Success criteria for this demonstration will be link closure supported by successful two-way communications between Ground Control and the LPT. The return link will be verified upon receipt of UDP/IP packets containing LPT and CANDOS Processor status, while the forward link will be verified by successful manipulation of the CANDOS Processor file system (using applications such as FTP for file transfer).

2.2.3 On-Orbit Reconfiguration

Two long-duration, approximately 45-minute, SN passes using one TDRS spacecraft have been allocated in order to demonstrate the ability to reprogram the LPT while on orbit. The LPT can store two complete images of its internal firmware. For purposes of this demonstration, the LPT will be launched with identical versions of firmware programmed into both memory banks. Once it has been established that the LPT is functioning as anticipated, and barring some form of damage to one of the two flash memory banks, the unused memory bank will be reprogrammed, using FTP, with a “slightly” modified version of firmware and rebooted. The demonstration will be deemed successful if the procedure is completed and the new firmware operates as anticipated.

2.3 Navigation Experiments

The LPT receives and processes code and carrier signals from up to 8 GPS satellites simultaneously. These signals include the navigation ephemeris message and the almanac data. In addition, the LPT will extract pseudorange and carrier phase measurements from the GPS signals.

The LPT’s GPS receiver will always be active and enabled, providing tracking resources for up to 8 signals simultaneously. Upon application of power to the LPT, a cold-start acquisition process is initiated that attempts to fill all GPS receiver channels. As long as at least one signal is acquired during this period, the LPT Control application running on the CANDOS Processor will process the recovered almanac and direct acquisition of new signals as the satellites come into view. Metrics generated by the LPT, and the GPS ephemeris recovered from each signal, are initially processed to form a point solution. Once this initial estimate is created, the GEODE application processes subsequent metrics and ephemerides in order to estimate the orbit of the Shuttle.

Nominally, GEODE will be executed such that it produces a new state vector every 30 seconds. For each call made to the GEODE application, the set of ephemerides, the receiver metrics (pseudorange), the updated point solution, and the resulting state vector solution will be time-tagged and stored as a file to the solid state disk. During periods of SN or GN communications, these archived data files will be retrieved and re-processed on the ground. The on-orbit results will be compared with the Flight Dynamics Facility (FDF) estimates and the ground-processed estimate. Success criteria for this demonstration will be on-orbit results that match ground based results to an acceptable degree of accuracy.

3. Role of Software Radios in the Space Internet

3.1 Software Radio Capabilties

Reconfigurable software radio technology provides an opportunity to implement new spacecraft data system architectures that can support internetworking in space and on-board spacecraft. Traditionally, space telecommunications equipment have been hardware-specific devices limited to executing physical and data link layer processes with limited capability to support networking and higher level functions. In contrast, a software radio performs functions that are traditionally carried out solely in hardware, such as the generation of the transmitted radio signal and the detection and demodulation of the received radio signal, by using software residing in high-speed digital signal processors. Since these functions are carried out in software, the radio can be programmed to transmit and receive virtually any desired transmission format. The operating parameters can be altered even after it is deployed by a software change.

The key component of a software radio is an architecture, as shown in Figure 4, that uses high speed digital signal processing to perform signal transmission and reception. The basic radio architecture features digital signal processing that can be implemented using different devices including Field-Programmable Gate Arrays (FPGAs), microprocessors, and digital signal processing chips. The significant level of digital processing available to a software radio allows it to perform higher level functions in addition to the basic waveform processing. For example, as discussed in Section 2, the LPT, is performing navigational functions for the CANDOS project. This higher-level processing can also be applied to networking operations.

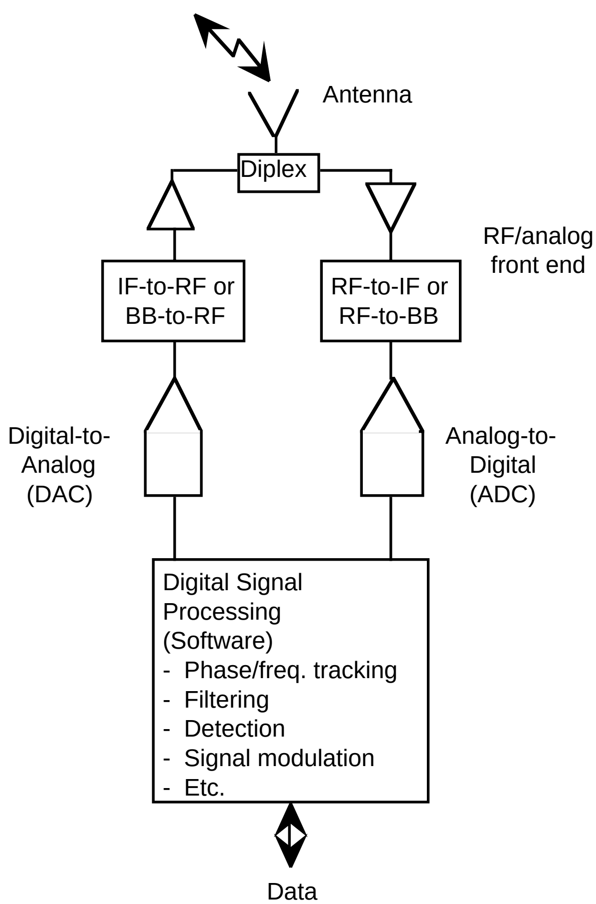

Figure 4. Fundamental Software Radio Architecture

3.2 On-board Spacecraft Internet Routing

The programmable nature makes software radios, including the LPT, ideal candidates for other tasking beyond that of communications and navigation. The unused processing capacity can support a network routing function for inter-satellite and intra-satellite communications. The software radio can serve both as a router for intra-spacecraft communications and as a node on the space Internet.

A future on-board spacecraft architecture features a software radio, such as the LPT, as the central node of an intra-satellite Local Area Network (LAN) consisting of the various instruments and control equipment nodes situated on the spacecraft. Figure 5 illustrates an example future spacecraft LAN architecture where each "smart" instrument and sub-system have unique IP addresses. Such an architecture supports distributed computing and spacecraft operations and it would also enable the use of the Internet for "virtual integration" between remote locations. The software radio serves both as a router to handle communications to the spacecraft nodes and as a gateway between the spacecraft LAN and the space or ground network. As network modules, software radios must perform the necessary networking features of routing, protocol translation, encoding/decoding, encryption/decryption, health monitoring, and synchronization along with its communication functions.

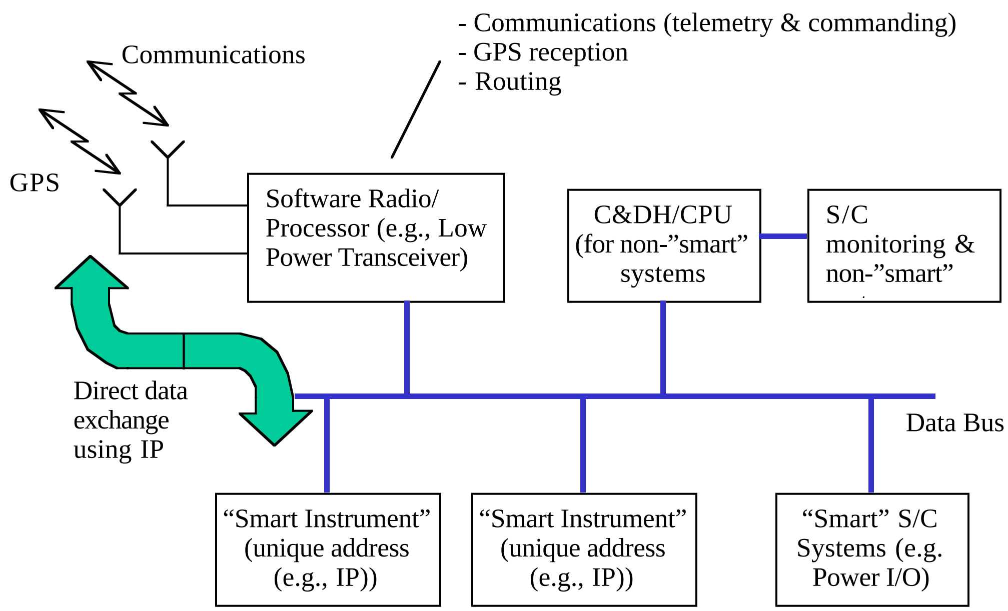

Figure 5. Example Distributed Spacecraft Communication Architecture

The key to such an architecture is a space qualified router to serve as the central spacecraft node. Although software radios are becoming widely used in industry and commerce, additional work needs to be conducted to prepare these radios for the space environment and for on-board applications. Key issues that need to be developed for software radios to serve as on-board routers include:

- *Radiation Tolerance.* The digital signal devices used in software radios are susceptible to single-event-upsets (SEUs) and single-event latchup (SEL) in the presence of radiation. Methods to overcome these problems include radiation tolerant devices and architectures that use redundancy.
- *Power Consumption.* The digital signal devices, especially microprocessors, used in software radios often require significant power, relative to available resources. Finding low-power approaches are required.
- *Standard Interfaces and Protocols.* Enabling on-board LAN architectures requires standard physical and data link interfaces that allow network layer (IP) operations with a wide-range of